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Multipath Routing – A Cross-Layer Design Tool for QoS Provisioning in MANETs

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Quality-of-Service in MANET

- **The goal** is to support real-time (interactive) applications in mobile ad hoc networks with
  - "guaranteed" timely delivery
  - data protection against channel impairment
  - load balancing

- **Why this is a new problem? (i.e.,** QoS in MANET vs. QoS in infrastructure-based wireless networks)
  - MANETs are multi-hop based
  - no infrastructure, no central entity
  - frequently changing topology with wireless connectivity

Effects of Mobility in MANET

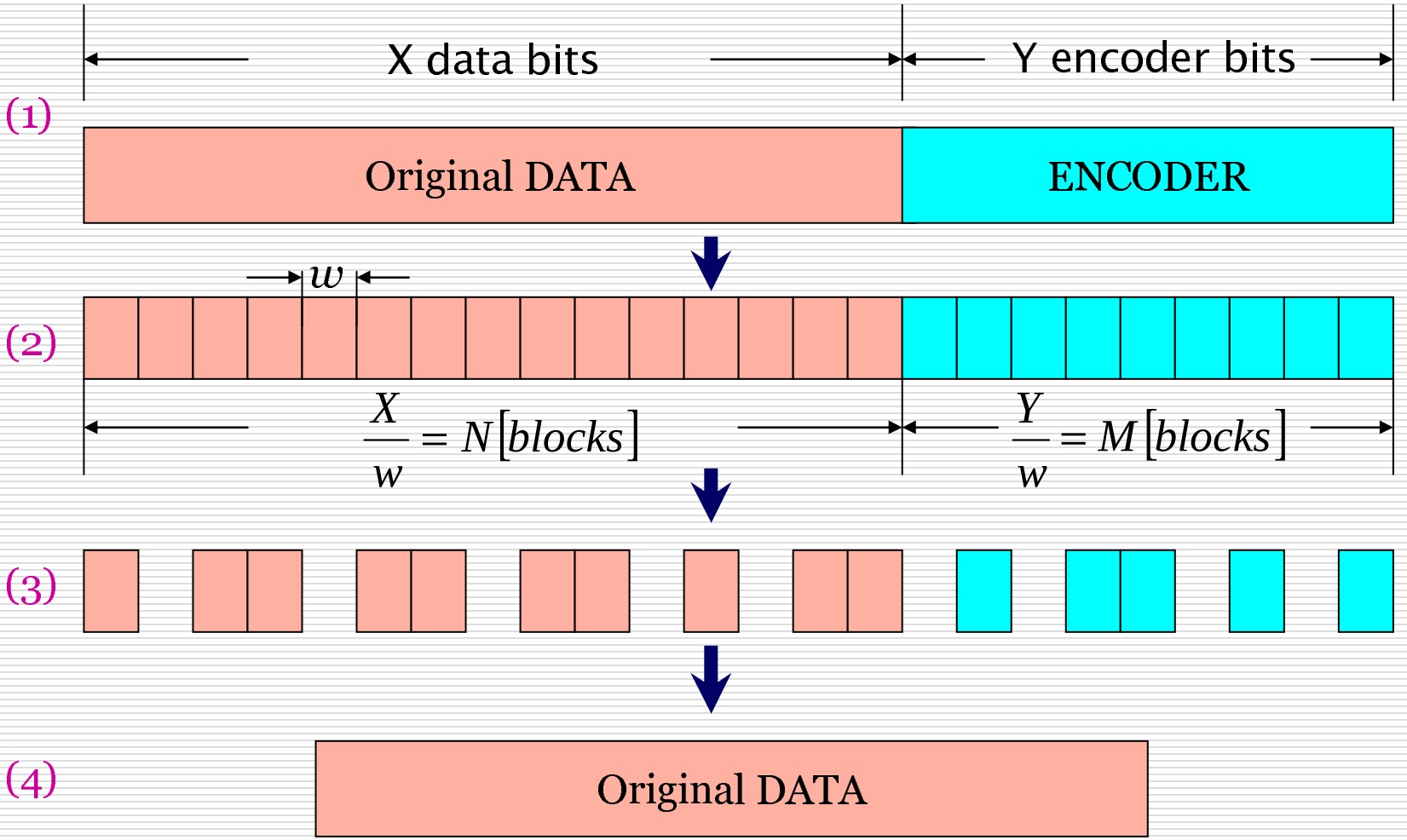
- **Negative impact**
  - Routes frequently break, leading to disruption in trafffic interactivity
  - Increased signaling overhead (e.g., due to route rediscoveries)
  - Increased loss of packets in transit
- **Positive impact**
  - Elimination of suboptimal route due to frequent route rediscovery
  - Improvement in per-node capacity under certain mobility models [Grossglauser and Tse, 2002]

Multipath Routing in MANET

- *Multipath Routing* is one candidate for QoS provisioning in MANET
- It is implemented through the Diversity-Coding (DC)

  [***A. Tsirigos and Z.J. Haas, ``Analysis of Multipath Routing - Part I: The Effect on the Packet Delivery Ratio," IEEE Trans. on Wireless Comm., vol. 3, no. 1, January 2004***]
- *Multipath Routing can* support numerous QoS features; for example:
  - improved path reliability (i.e., protection against frequent path breakages)
  - improved data transmission security in ad hoc networks [Papadimitratos and Haas, 2003]

Principle of M-for-N Diversity Coding

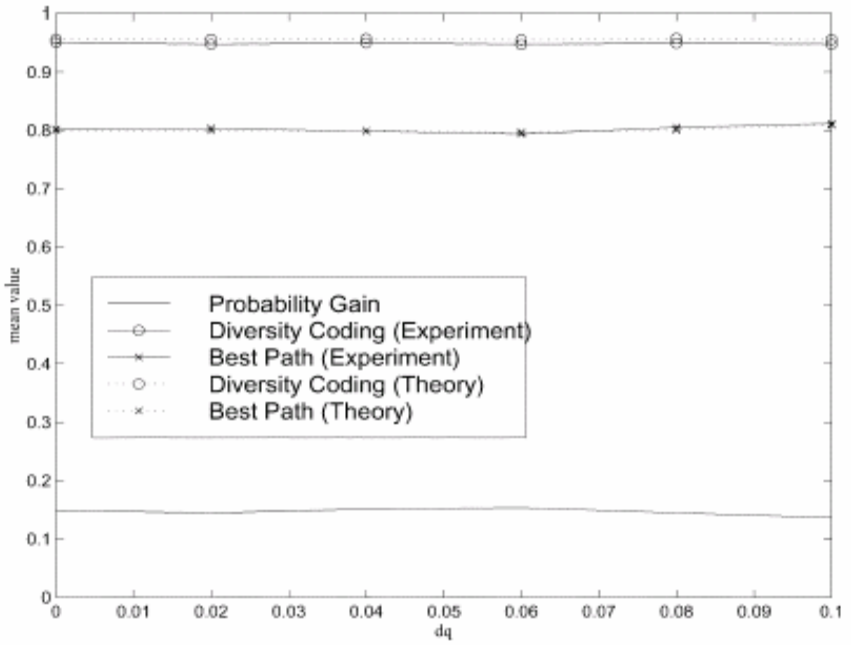


Diversity Coding based Multipath Routing

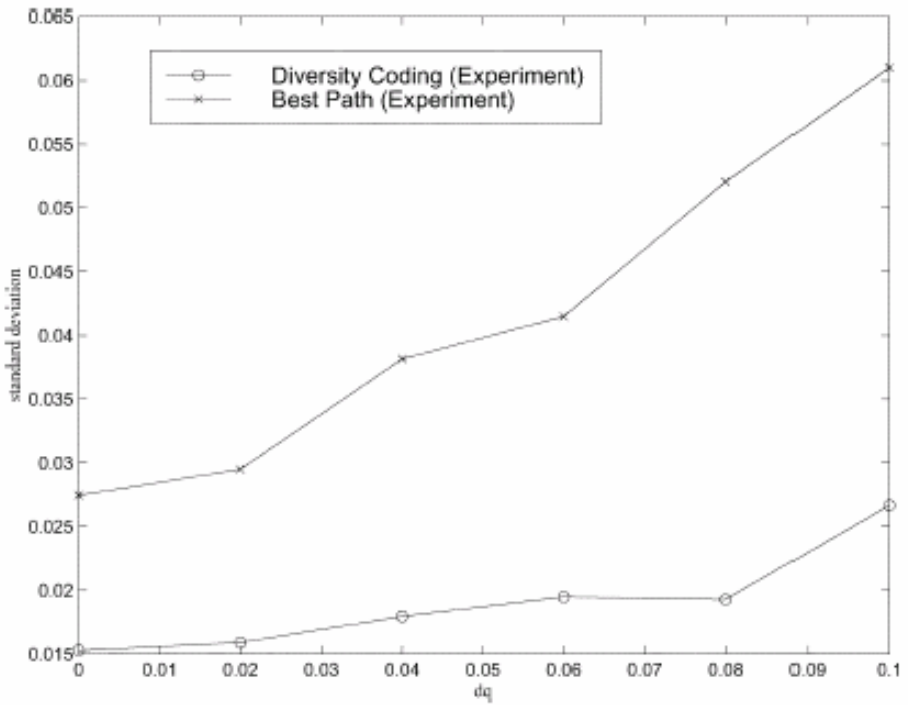
Feature of *Diversity Coding* (DC)

- **Loss tolerance:** DC allows some block loss during transmission (up to M blocks in *N:M Diversity Coding*)
- **Data re-construction:** DC allows to fully re-construct original data at the destination
- **Block Design Objective:** to maximize the probability that the original data is fully re-constructed at the destination, P_{succ}
- **Path selection:** to select the most reliable paths that achieve the above objective
- **Packet allocation:** to allocate more packets on more reliable paths (i.e., non-uniform packet allocation)

DC-based Multipath vs. Single-path Routing (Independent Paths)



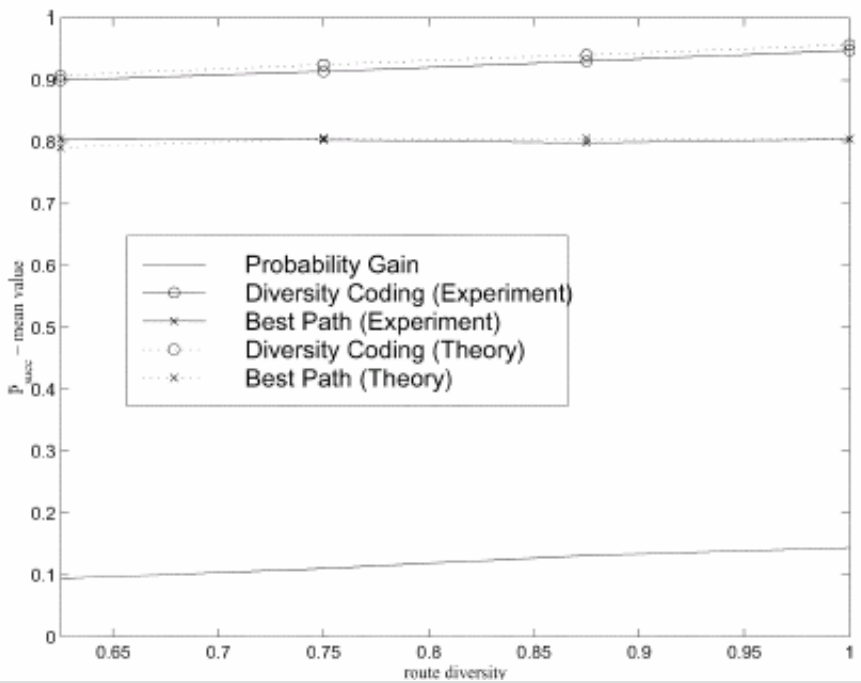
Mean P_{succ} and probability gain



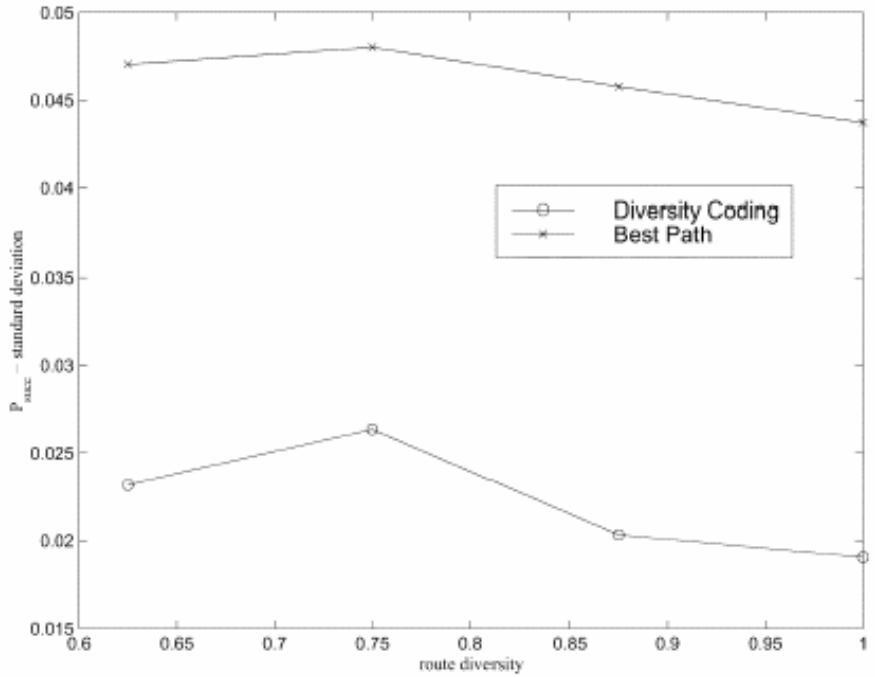
Standard deviation of P_{succ}

Probability gain: the difference in mean P_{succ} between DC and single, best path routing

DC-based Multipath vs. Single-path Routing (Correlated Paths)



Mean P_{succ} and probability gain



Standard deviation of P_{succ}

Route diversity: the degree of correlation between the paths in the path set

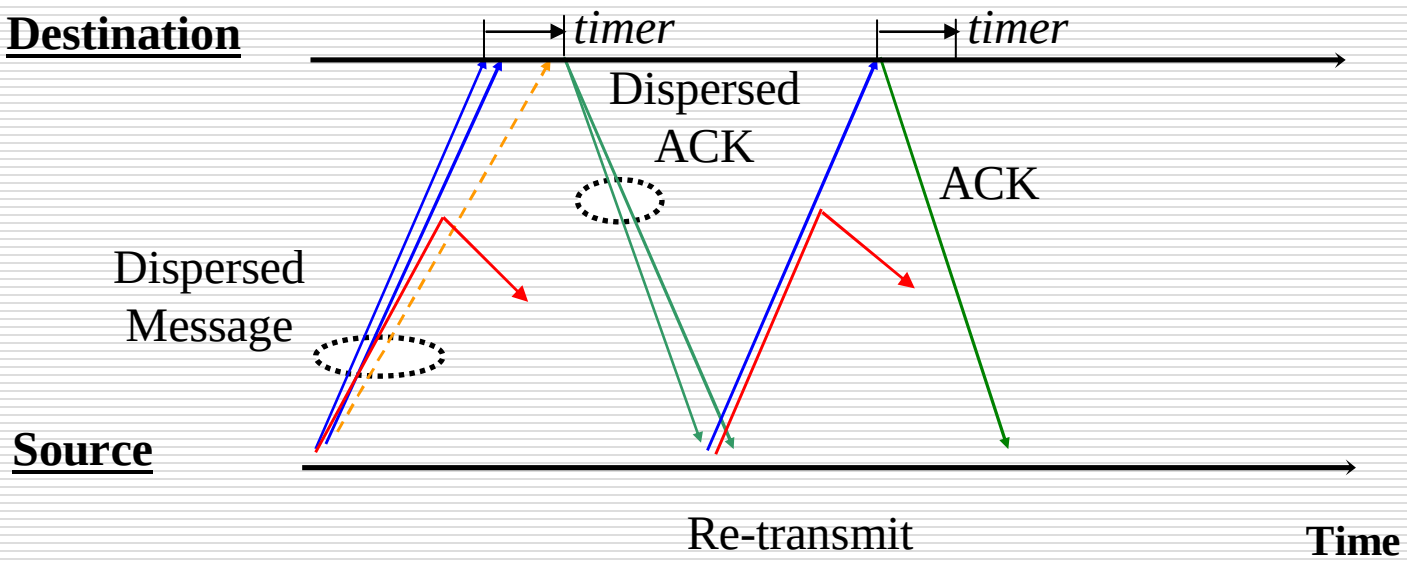
Use of Multipath Routing and DC for Secure Message Transmission in Ad Hoc Networks

- Supporting security in ad hoc networks is a major challenge, due to:
  - Lack of central entity (i.e., no single entity that every node trusts)
  - Frequent changes of network constituency and topology
- Multipath Routing with DC is used to support security by:
  - Dispersion of the transmitted data
  - Simultaneous usage of multiple, node-disjoint routes
  - Data integrity and origin authentication
  - End-to-end secure and robust feedback
  - Adaptation to the network conditions

The above scheme is called the *Secure Message Transmission (SMT)* protocol

Transmission of a Message with *SMT*

An example of the use of Multipath Routing and DC for secure message delivery in *SMT*:

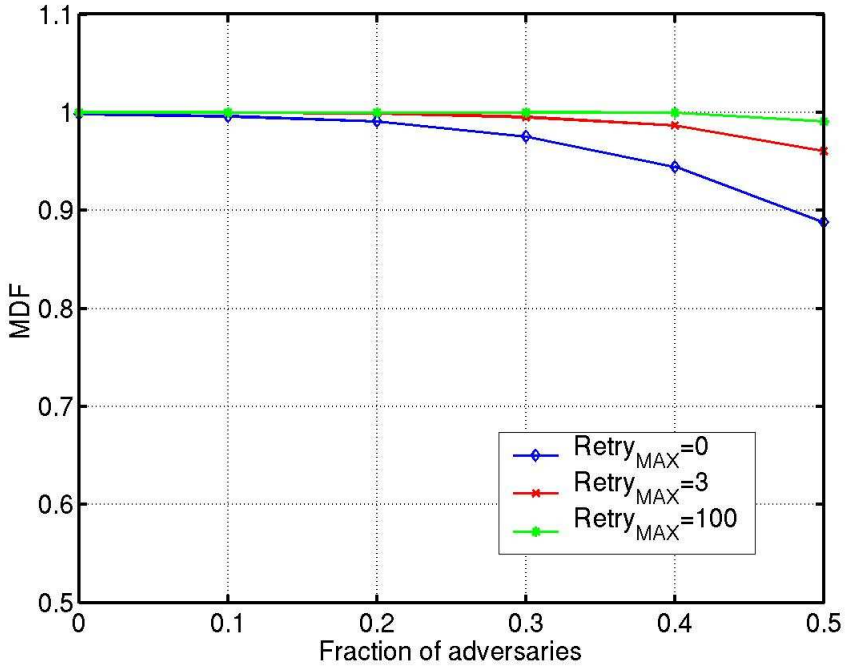


Implementation of *SMT*

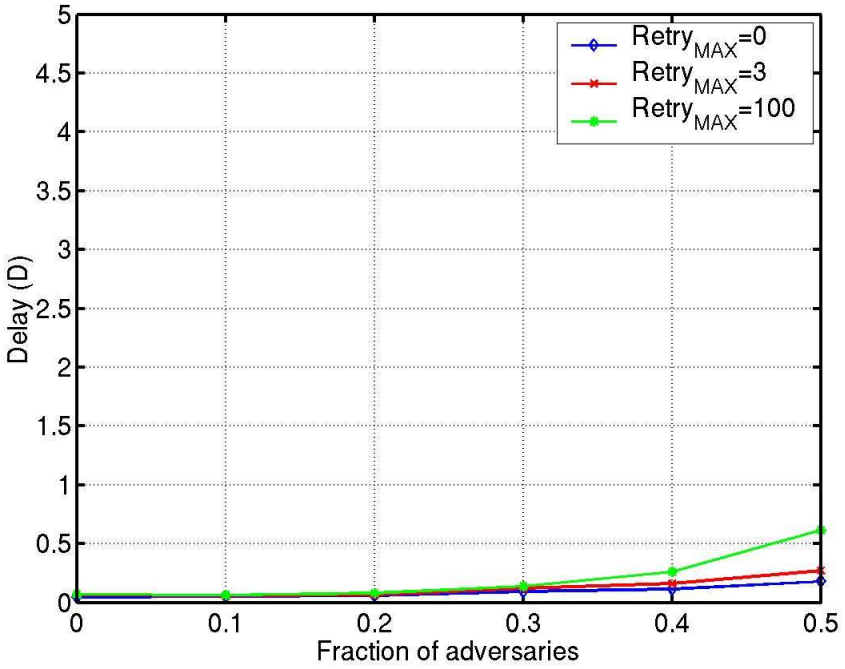
- *SMT* operates on top of any secure routing protocol that can discover multiple routes (e.g., the *Secure Routing Protocol*)

  [P. Papadimitratos and Z.J. Haas, "Securing Mobile Ad Hoc Networks," *The Handbook of Ad Hoc Wireless Networks*, CRC Press 2003]
- *SMT* requires a single end-to-end security association (no need for intermediate security assn.)
- *SMT* secures the communication, providing reliable and low-delay data delivery
- *SMT* shows resilience to a significant fraction of Byzantine adversaries
- *SMT* generates only moderate excessive network overhead

SMT Performance Evaluation (I)



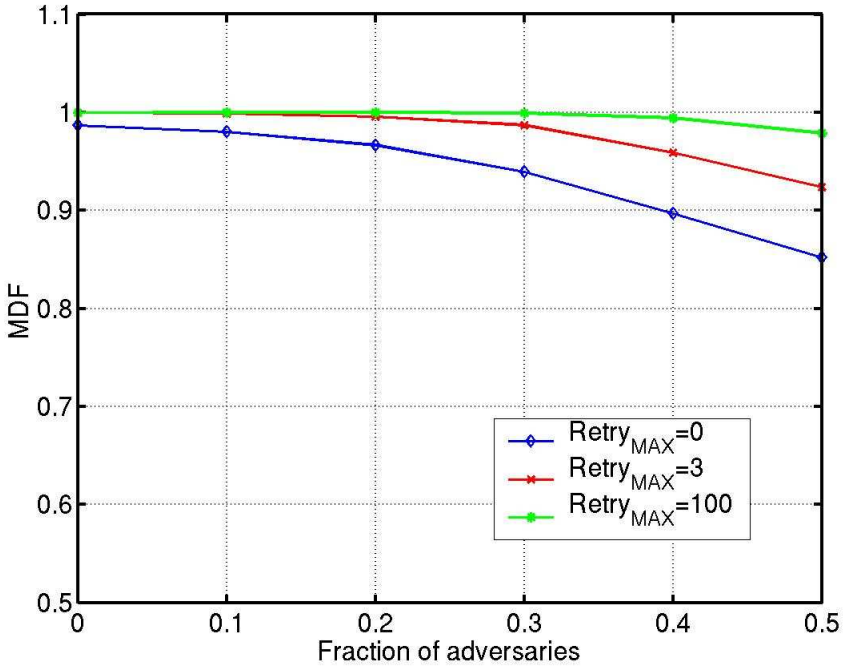
Message Delivery Fraction

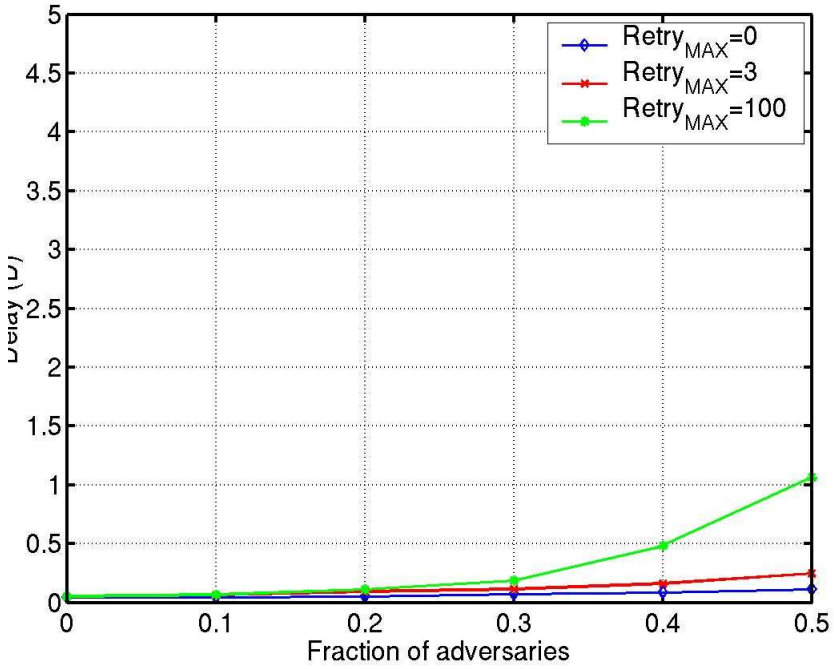


Message Delay

SMT-LS: SMT with a Link State Protocol

SMT Performance Evaluation (II)





Message Delivery Fraction

Message Delay

SMT-RRD: SMT with Secure Routing Protocol

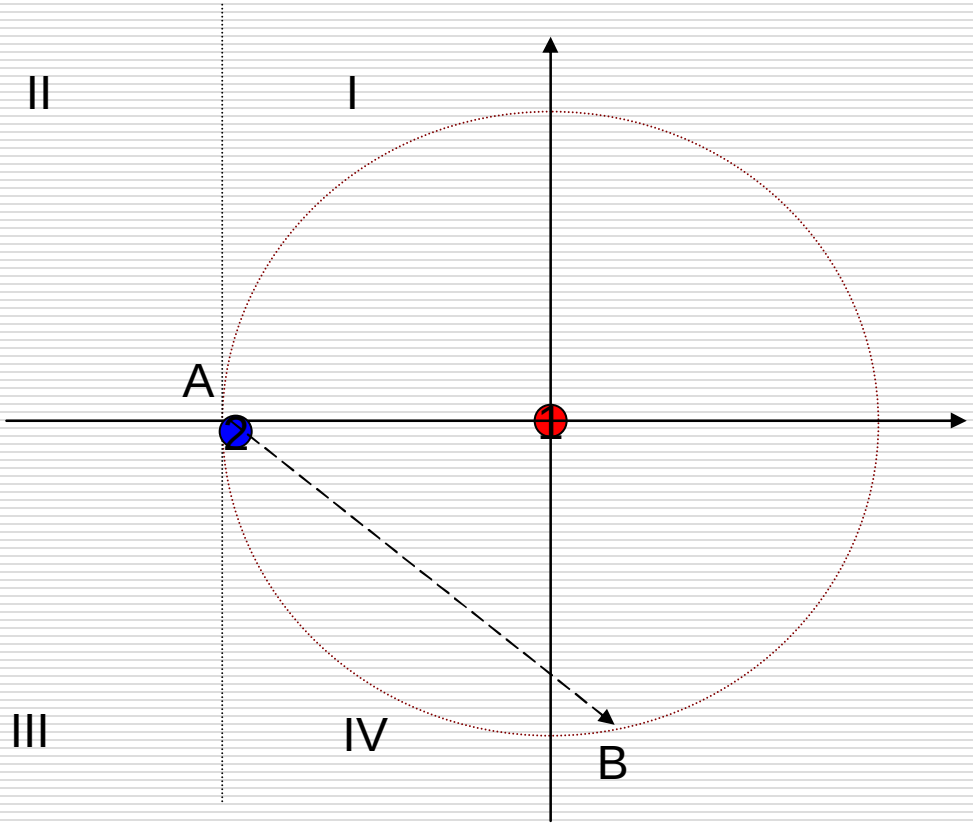
Analyzing DC: Understanding Path Lifetime in MANET

- The first step in analyzing DC is the study of path lifetime
- Lifetime Y of a L-hop path equals to the lifetime of the shortest-lived of all constituent links X_i on the path

$$Y = \min(X_1, X_2, ..., X_L)$$

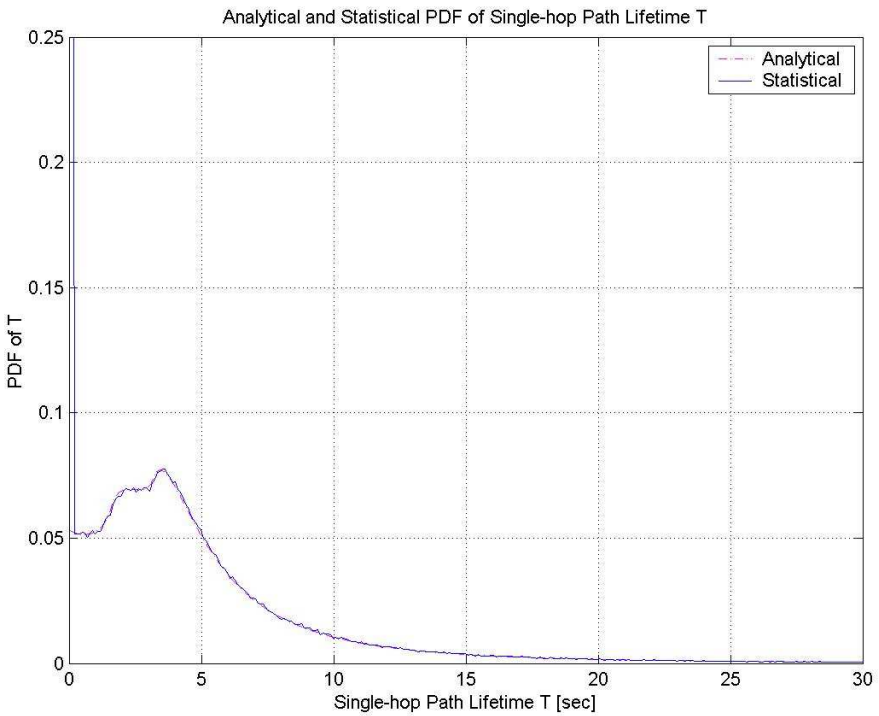
- Difficult to model analytically the lifetime of a (multi-hop) path in the MANET with realistic assumptions
  - Most study of path lifetime done in simulations
- Some observations
  - Nodes on a path exhibit correlation that compromises path lifetime
  - This correlation is proportional to the Euclidian distance between two neighboring nodes
  - Greater Euclidian distance skews PDF towards t=0 [sec]

Analyzing Path Lifetime: the two-node link model



Link Lifetime: the duration of time for the blue node to traverse from Point A to Point B, within the transmission range of the red node

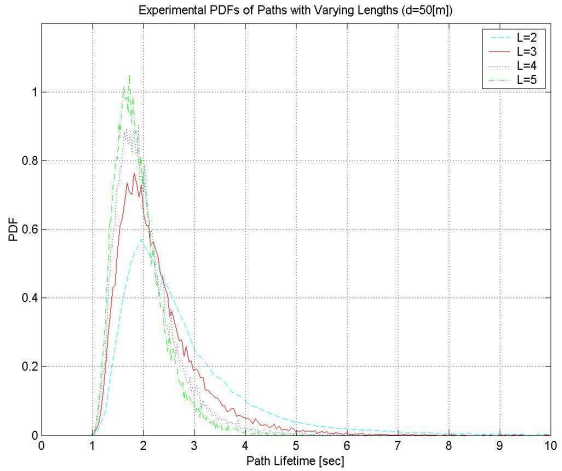
Analyzing Path Lifetime: The *pdf* of single-hop path lifetime

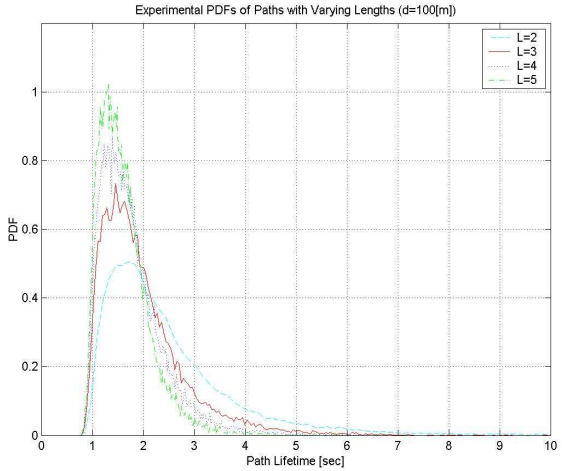


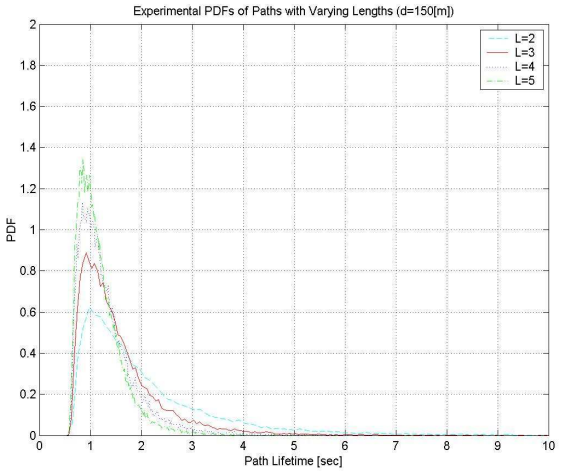
Analytical and statistical PDF of a single-hop path lifetime

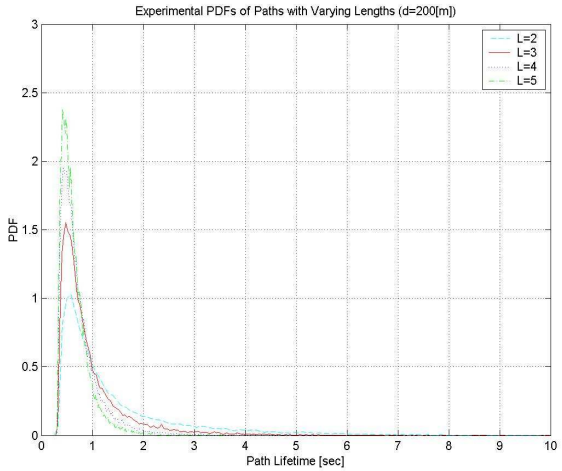
- Assumed co-dependence between direction and magnitude of a node velocity
- Analytical *pdf* is in a closed-form expression

Statistical *pdf* of Multi-hop Path Lifetime with Respect to Distance between Nodes









Note: hops of the path assumed to be equidistant

Summary

- *Multipath Routing (MR),* together with *Diversity Coding (DC),* creates a **cross-layers mechanism** that allow to support numerous Quality-of-Service features in ad hoc networks.
- In particular, the *MR/DC* scheme allows to support highly reliable communication environment, suitable for interactive real-time communication across a highly unreliable ad hoc network.
- As another example, the *MR/DC* scheme can support secure communication environment.
- For maximum benefit, the *MR/DC* scheme requires cross-layers interaction between the MAC layer, the networking layer, the transport layer, and the application layer.
- We are currently evaluating the model of the *Multipath Routing/Diversity Coding* scheme, both analytically and through simulations.

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